Current Offer Structure and Pricing Outcomes for Reserves

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Agenda

- Recap of Offer Parameter
- Resource reserve capability calculation(s)
- Reserve clearing examples and pricing outcomes
- Operational Reserves vs. Dispatched Reserves

Recap: Offer Parameters

Parameter	Reserve Market	RESOURCE TYPE				
		Condensers	Other Gen	Wind/Solar/ Nuclear	ESR/Hydro	Load Response
SR/SecR Max*	SR	Yes, if qualified via existing process				N/A
	NSR	N/A***				
	SecR	Yes, if qualified via existing process				N/A
Offer MW	SR	No	No	No	Yes	Yes
	NSR	N/A			Yes (N/A ESR)	N/A
	SecR**	No	No	No	Yes	Yes
Offer Price	SR	Yes, cannot exceed expected value of Synchronized Reserve Penalty				
	NSR	N/A				
	SecR	N/A				

*SR Max and SecR Max are both able to be updated intra-hour; requests to submit a value lower than Eco Max must be sent and approved by PJM and IMM

**Offer MW can be updated up to 65 mins prior to start of operating hour ***NSR capability capped by SR Max, as applicable

Reserve Capability vs Reserve MW

Resource Reserve Capability MW	Resource Reserve MW
The quantity of reserve MW ***assumed*** a resource can provide within the product response time	The quantity of reserve MW ***assigned*** to a resource for the product response time based on the system economic *Quantity is capped at the estimated capability*

Uses resources modeling parameters for energy and reserve as provided by resource owner

See Reserve Market Overview: slides 20 – 31, and Manual 11: Section 4.2.5

Quantity can be overstated or understated	• Based on the initial energy MW for online generating unit • Uses average of segmented ramp rate
Quantity is more accurate but capped at capability MW	• Based on the dispatched energy MW for online generating unit • Uses time weighted segmented ramp rate

This presentation will discuss Reserve MW further since the IMM presentation is already focused on Reserve Capability MW and Ramp Rate

Summary of Reserve Capability Calculation Parameters

Resource Type or Operating Mode

Reserve Product	Condensers	Flexible Generator		ESR, Hydro, Hybrids	Economic Load Response
SR	(A) ramp rate; (B) condense to generation time (C) Economic Minimum; and (D) the lesser of Eco Max and SR Max	(A) Initial MW (B) ramp rate; (C) Eco Min; and (D) the lesser of Eco Max and SR Max		Use SR Offer MW Constrained by Eco Limits	
NSR	(A) startup time; (B) notification time; (C) ramp rate; (D) Eco Min; and E) the lesser of Eco Max and SR Max ▲			Use NSR Offer MW for Hydro Constrained by Eco Limits	No – ELR and ESR are ineligible for NSR
SecR	Not Applicable	**Online** (A) Initial MW (B) SR MW (C) ramp rate (D) Eco Min (E) the lesser of Eco Max and SR Max	**Offline** (A) NSR MW (B) startup time (C) notification time (D) ramp rate (E) Eco Min (F) the lesser of Eco Max and SR Max ▲	Use SR Offer MW Constrained by Eco Limits	

▲ ***Soak Time assumed to be zero***

Synchronized & Secondary Reserve Maximum

Parameter	
Synchronized Reserve Maximum (SR Max)	Upper limit for SR procurement
Secondary Reserve Maximum (SecR Max)	Upper limit for SecR procurement

SR Max and SecR Max parameters are optional in Markets Gateway	**SR Max and SecR Max values** are set to Eco Max in the market clearing engine unless an exception is approved	**SR Max and/or SecR Max** can be lower than Eco Max if physical or operational limitation exist on the unit as detailed in Section 4.2.2.1 of Manual 11	Currently **31 units are approved** to use a SR Max less than Eco Max

Limitation exist but not communicated or approved SR Max = EcoMax	**Limitation exist,** communicated and approved SR Max <= EcoMax

SR MW Calculation Example

Flexible SR & No Ramp Constraint | Approved SR Max < Eco Max

Energy + AS ≤ Min [Eco Max, SR Max]

Eco Min = 404 MW

Eco Max = 875 MW

SR Max = 865 MW

Parameters	Scenario 1	Scenario 2	Scenario 3
SE MW	820	860	870
Target MW	850	870	837
SR MW	15	0	28

Key Takeaway	**Resource may be considered for reserve** when the target energy MW is below SR Max	**No reserve consideration** because energy target MW is above SR Max	**Reserve MW materializes at the target MW:** *For a downward dispatch, potential issue exist if Spin Event called before energy target time or if unit not following dispatch*

SR MW Calculation Example

Eco Min =
25 MW

Eco Max =
100 MW

Condensing SR | Ramp Rate = 10 MW/Min			
Status: Online Condensing: -0.2 MW			
Parameters	**Scenario 1**	**Scenario 2**	**Scenario 3**
Condense-to-Gen Time	0	8	> 10
SR MW	100	45	0

SR MW Capability = max{0,min [min(Eco Max, SR Max), Eco Min + RR x (10 min – Condense to Gen Time)] }

Key Takeaway	**Accurate modeling parameter** results in realistic expectation	**Spin Event that ends in less than 8 min** makes the unit looks like poor performer – managing expectation

SR MW Calculation Example

EcoMin = 10 MW

EcoMax = 100 MW

SR Offer = 30 MW

Hydro and Pump Storage

Resource must self submit Reserve Offer MW

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4
SE MW	20	50	80	80
SR Max	60	70	70	Null or Eco Max
SR MW	30	20	0	20

SE MW + Reserve MW ≤ Min[Eco Max, SR Max]

Key Takeaway	**SR Max timely update** is crucial *(See scenario 3 & 4)*	**Quantity of reserve MW** assign to can be limited by the SE MW and the Reserve Offer MW for non-dispatchable Hydro unit	Reserve MW ≤ Reserve Offer MW

Synchronous Condensers Overview

A synchronous machine whose shaft is not attached to any driving equipment and is able to provide reactive power support or synchronized reserve

Condense Available: for reactive or voltage support;

Reserve As Condenser: to provide Synchronized Reserve

Condensing Mode

- Condense Energy Usage in MW;
- Condense Notification Time (< 30 minutes)
- Condense to Generate Time (< 10 minutes)
- Minimum Run Time (<= 1 hour)
- Condense Startup Cost

Generating Mode

Able to provide energy or flexible reserves

During an Synchronized Reserve Event, the condenser flips from condensing mode to generation and returns to condensing immediately after the event or after its min run time has been met.

Recap: Flexible and Inflexible Reserve Resources

Attributes	Inflexible Reserve	Flexible Reserve
Resource Types	• Resources that can operate in condensing mode • Economic Load Response (ELR)	• Online/offline generating resources • Some Economic Load Response (based on request by Participant)
Clearing Methodology	DA, ASO	DA, RT SCED
Minimum Commit Time	One hour	One hour in DA, Five minutes in RT
Start Up + Notification Time	30 Minutes or Less	30 Minutes or Less
Assignment Communication	30 minutes ahead of operating hour in the Award page of Markets Gateway and also in real-time via ICCP/DNP and the Dispatch Lambda page of Markets Gateway	In real-time via ICCP/DNP and the Dispatch Lambda page of Markets Gateway

Market Clearing Engines & Clearing Principles

Day-Ahead
1 Day Ahead

- ••Clears Reserve Requirements using both inflexible and flexible SR
- ••DA commits all cleared SR
- ••Financially binding but not obligated to respond to Synchronized Reserve (SR) Event

ASO
1 Hour Ahead

- ••Honors inflexible SR committed from DA
- ••Clears the balance of Reserve Requirement MW using both inflexible and flexible SR.
- ••Commits inflexible SR only

IT SCED
30 Minutes Ahead

- ••Honors inflexible SR from ASO
- ••Clears balance of Reserve Requirements using both inflexible and flexible SR
- ••Recommends additional inflexible SR which can only be manually committed by dispatchers

RT SCED
10 Minutes Ahead

- ••Honors inflexible SR logged from upstream (ASO and manual commitments)
- ••Clears the balance of Reserve Requirement MW using ONLY flexible SR
- ••Commits flexible SR only

LPC
5 Minute Pricing

- ••5-minute energy and reserve pricing
- ••Based on latest approved RT SCED case for the target interval
- ••Fast Start pricing logic for eligible resources providing Energy may affect reserve pricing
- ••Applies administrative energy and reserve price capping

Real-Time Committed SR (flexible and inflexible) effective at the initiation of an SR Event is obligated to respond

Current Offer Structure

Synchronized Reserve Offer ($/MWh) capped at expected penalty	• Currently 0.04 $/MWh (vs. $7.50 margin adder pre RPF)	• Must Offer Requirements • No Offer Price for NSR, SecR
Reserves and Energy are co-optimized in both DA and RT	• No LOC associated with NSR or offline SecR	
MCP = Effective Cost of the marginal resource providing reserve to meet requirement	• When NSR MCP or SecR MCP is non-zero, additional SR MW has been committed to meet the Primary or 30 Minute service requirement	• ORDCs set requirement and price • Penalty factors apply in cases with shortage conditions

Effective Cost Calculation

Resource Type	Effective Cost
Online flexible resources	SR Offer Price + Abs(PSC)
Inflexible Reserve Condensing	SR Offer Price + EUCOST
Demand Response Resource	SR Offer Price
Hydro	SR Offer Price + Average Value of Water

Product Substitution Cost (PSC) is an outcome of the joint optimization between energy and reserves	**Condense Energy Usage Cost (EUCOST)** is equal to (LMP * Energy Usage MW) / SR Capability
Average Value of Water – see Section 3.2.8 of Manual 11 for equivalent details	

Day-Ahead Synch Reserve Clearing Example

Synch Reserve Requirement = 35 MW; **Market Hour** = Hour Ending 11

Resource	In-Flexible	SR Capability, MW	Effective Cost, $/MWh	SR Cleared, MW	SR MCP, $/MWh
A	No	10	$0.10	**10**	**$0.20**
B	No	10	*$0.20*	**5**	
C	No	10	$0.30	0	
D	Yes	10	$0.15	**10**	
E	Yes	10	$0.50	0	
F	No	10	$0.10	**10**	

All eligible reserve resources are considered for clearing.

The Effective Cost is the sum of the resource-related offer costs plus opportunity cost from the joint optimization.

Resource B is marginal, and sets DA SR MCP = $0.20/MWh, published and financially binding.

Real-Time ASO Synch Reserve Clearing Example

Synch Reserve Requirement = 35 MW; **Market Hour =** Hour Ending 11

Resource	In-Flexible	SR Capability, MW	Effective Cost, $/MWh	SR Cleared, MW
A	No	10	$0.80	0
B	No	10	*$0.70*	**5**
C	No	10	$1.20	0
D	Yes	10	$0.15	**10**
E	Yes	10	$0.60	**10**
F	No	10	$0.20	**10**

All eligible reserve resources are considered for clearing.

The Effective Cost is the sum of the resource-related offer costs plus opportunity cost from the joint optimization.

Resource B is marginal but no SR MCP is published from ASO and not financially binding.

Real-Time ITSCED Synch Reserve Clearing Example

Synch Reserve Requirement = 35 MW; **Market Interval =** 10:15

Resource	In-Flexible	SR Capability, MW	Effective Cost, $/MWh	SR Cleared, MW
A	No	10	$0.80	0
B	No	10	*$0.70*	**5**
C	No	10	$1.20	0
D	Yes	10	$0.15	**10**
E	Yes	10	$0.60	**10**
F	No	10	$0.20	**10**

All eligible reserve resources are considered for clearing.

The Effective Cost is the sum of the resource-related offer costs plus opportunity cost from the joint optimization.

Resource B is marginal but no SR MCP is published from ITSCED and not financially binding.

Real-time RTSCED Synch Reserve Clearing Example

Synch Reserve requirement = 35 MW | **Market Interval** = 10:15

Resource	In-Flexible	SR Capability, MW	Effective Cost, $/MWh	SR Cleared, MW
A	No	10	$1.80	0
B	No	10	$1.60	0
C	No	10	*$1.20*	**5**
D	Yes	10	$0.15	**10**
E	Yes	10	$1.40	**10**
F	No	10	$0.40	**10**

All eligible *flexible* reserve resources are considered for clearing

The inflexible reserve MW committed from upstream offsets the reserve requirement

The Effective Cost is the sum of the resource related offer costs plus opportunity cost from the joint optimization

Resource C is marginal but no SR MCP published from RTSCED

Real-time LPC Synch Reserve Pricing Example

Synch Reserve requirement = 35 MW | **Market Interval** = 10:15

Resource	In-Flexible	SR Capability, MW	Effective Cost, $/MWh	SR Cleared, MW	SR MCP, $/MWh
A	No	10	$1.80	0	**1.2**
B	No	10	$1.60	0	
C	No	10	*$1.20*	**5**	
D	Yes	10	$0.15	**10**	
E	Yes	10	$1.40	**10**	
F	No	10	$0.40	**10**	

Only eligible *flexible* reserve resources are considered for pricing

The inflexible reserve resources committed from upstream of RTSCED are not eligible to set reserve MCP

The Effective Cost is the sum of the resource related offer costs plus opportunity cost from the joint optimization

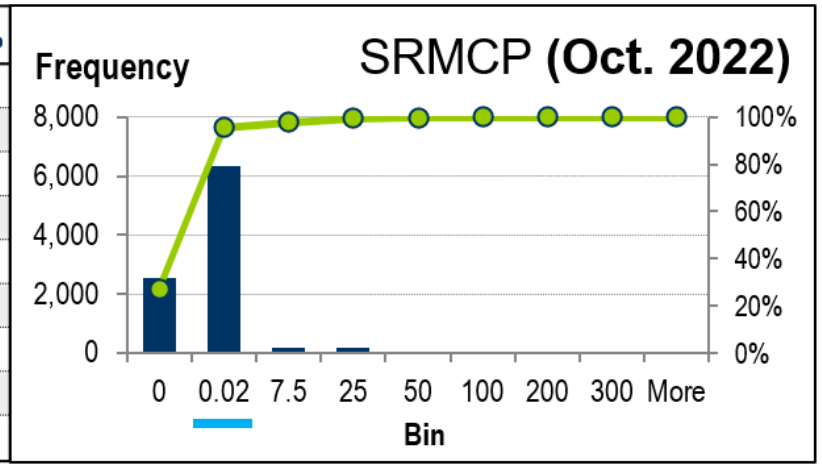
Resource C is marginal and sets the SR MCP that is published and used in Settlement

Determination of Reserve Clearing Prices

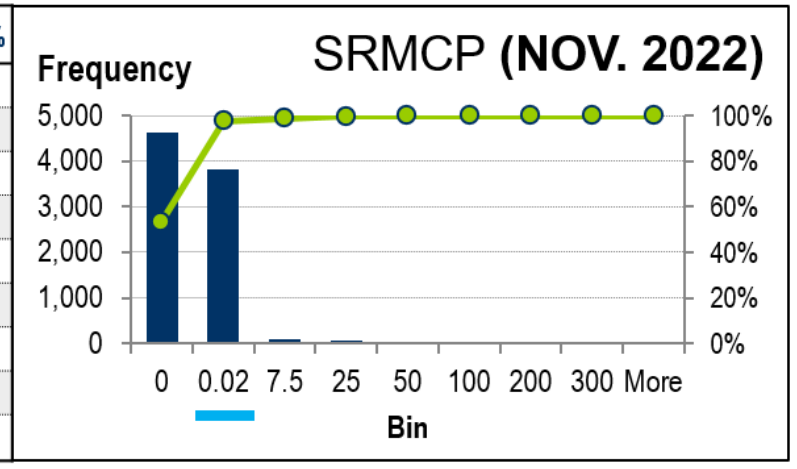
Clearing Price		Calculation
Secondary Reserve	=	Shadow Price of 30-Minute Reserve Requirement
Non-Synchronized Reserve	=	Shadow Price of Primary Reserve Requirement + Shadow Price of 30-Minute Reserve Requirement
Synchronized Reserve	=	Shadow Price of Synchronized Reserve Requirement + Shadow Price of Primary Reserve Requirement + Shadow Price of 30-Minute Reserve Requirement
Energy Price	=	Shadow Price of Power Balance Constraint (includes Reserve clearing price if marginal Energy MW comes from converting Reserve into Energy)

SRMCP Distribution & Histogram: Oct, 2022 – Jan, 2023

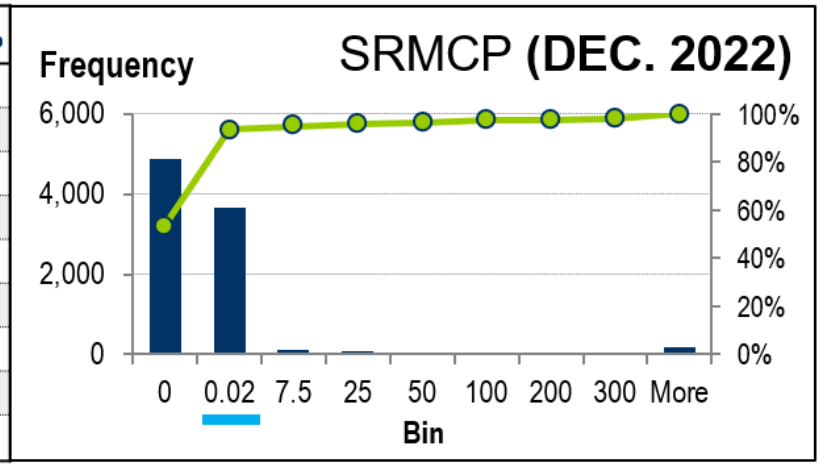
Price	Frequency	Cumulative %
0	2542	27.36%
0.02	6335	95.53%
7.5	179	97.46%
25	172	99.31%
50	37	99.71%
100	20	99.92%
200	4	99.97%
300	3	100.00%
More	0	100.00%



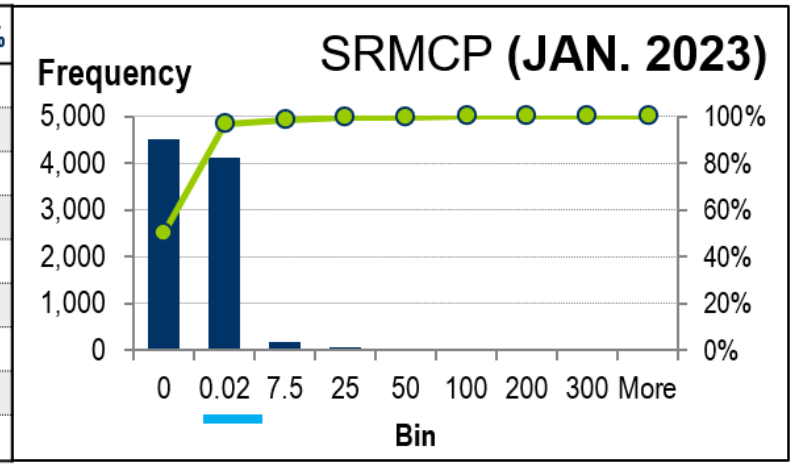
Price	Frequency	Cumulative %
0	4620	53.47%
0.02	3821	97.70%
7.5	86	98.69%
25	74	99.55%
50	27	99.86%
100	12	100.00%
200	0	100.00%
300	0	100.00%
More	0	100.00%



Price	Frequency	Cumulative %
0	4881	53.41%
0.02	3676	93.63%
7.5	123	94.98%
25	96	96.03%
50	45	96.52%
100	62	97.20%
200	27	97.49%
300	40	97.93%
More	189	100.00%



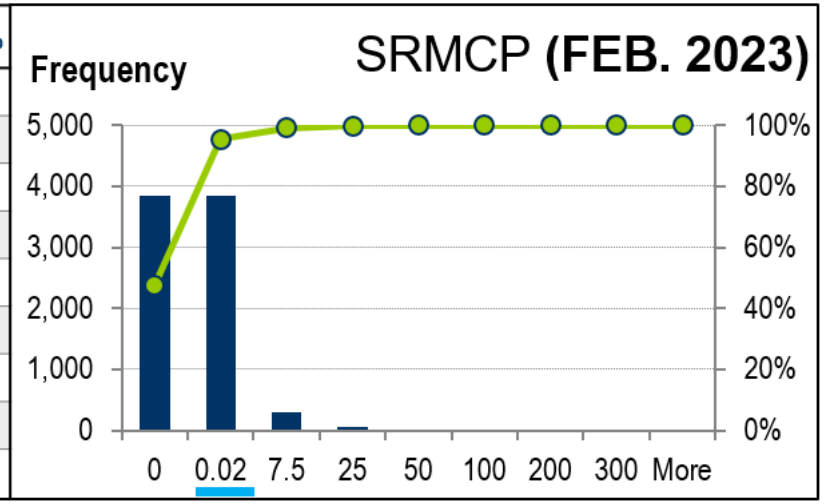
Price	Frequency	Cumulative %
0	4518	50.60%
0.02	4116	96.71%
7.5	163	98.53%
25	73	99.35%
50	30	99.69%
100	20	99.91%
200	5	99.97%
300	0	99.97%
More	3	100.00%



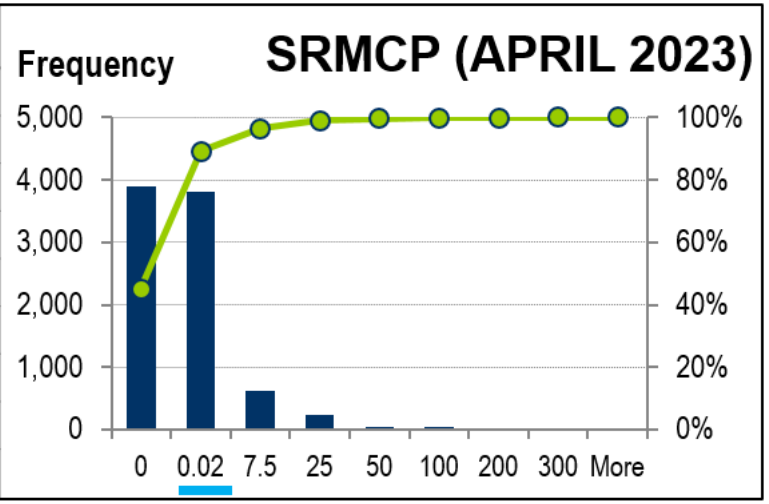
Key Takeaway: SRMCPs were less or equal to $0.02/MWh most of the time after RPF.

SRMCP Distribution & Histogram: Feb - May, 2023

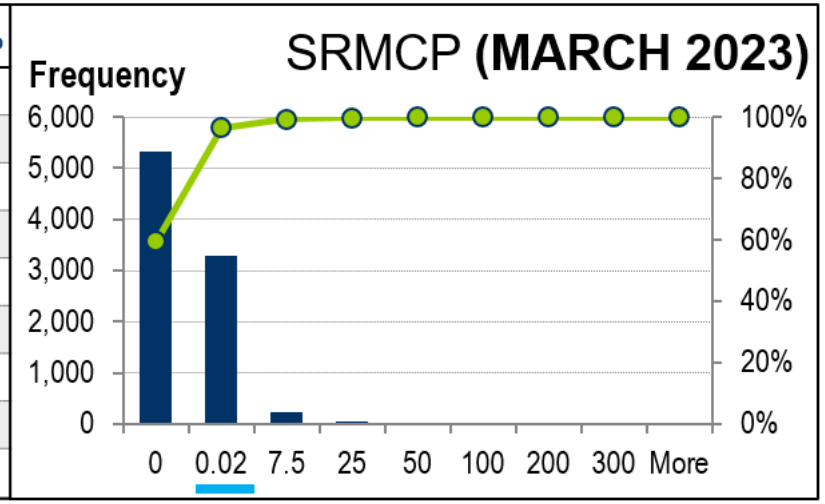
Price	Frequency	Cumulative %
0	3844	47.67%
0.02	3852	95.44%
7.5	296	99.11%
25	64	99.90%
50	6	99.98%
100	1	99.99%
200	1	100.00%
300	0	100.00%
More	0	100.00%



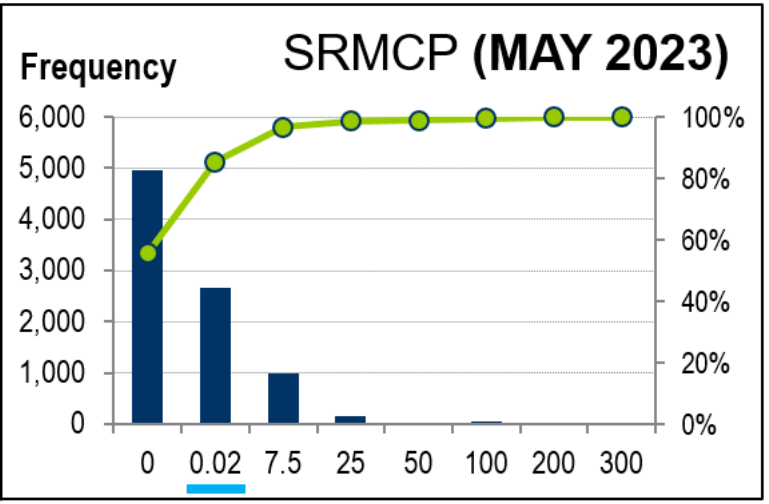
Price	Frequency	Cumulative %
0	3894	45.07%
0.02	3815	89.22%
7.5	621	96.41%
25	234	99.12%
50	39	99.57%
100	31	99.93%
200	4	99.98%
300	2	100.00%
More	0	100.00%



Price	Frequency	Cumulative %
0	5318	59.57%
0.02	3297	96.49%
7.5	242	99.20%
25	47	99.73%
50	14	99.89%
100	9	99.99%
200	1	100.00%
300	0	100.00%
More	0	100.00%

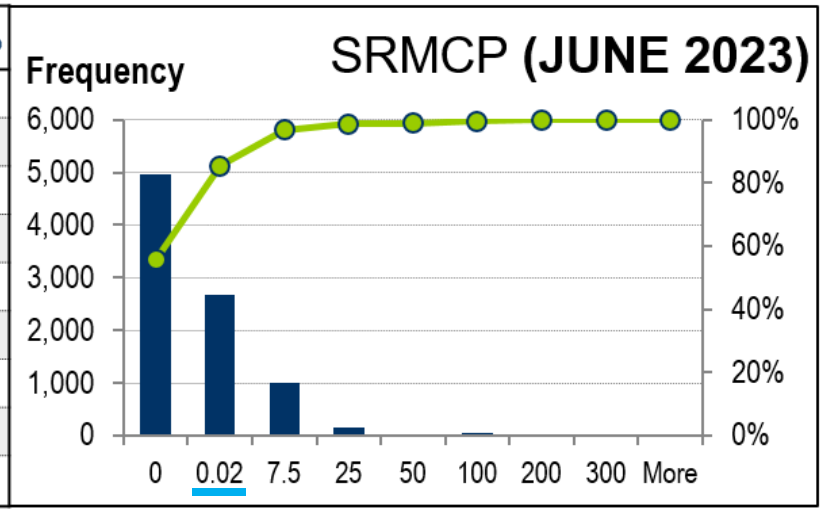


Price	Frequency	Cumulative %
0	4968	55.65%
0.02	2663	85.48%
7.5	1003	96.72%
25	165	98.57%
50	36	98.97%
100	51	99.54%
200	29	99.87%
300	12	100.00%
More	0	100.00%

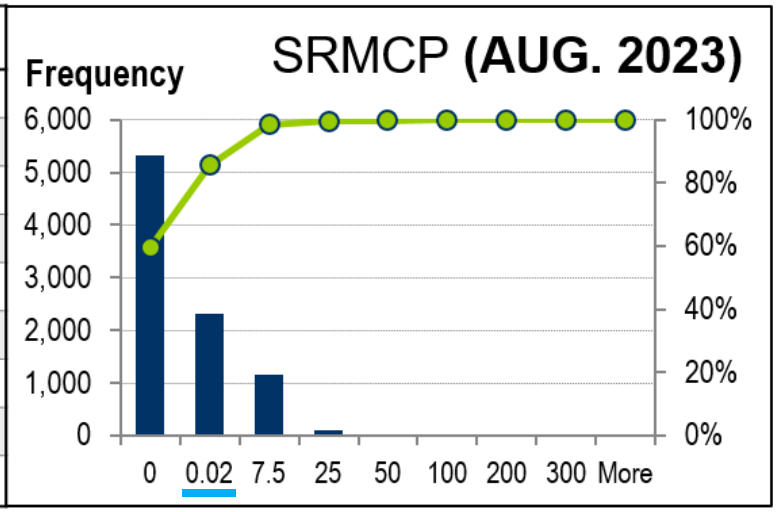


SRMCP Distribution & Histogram: Jun-Aug, 2023

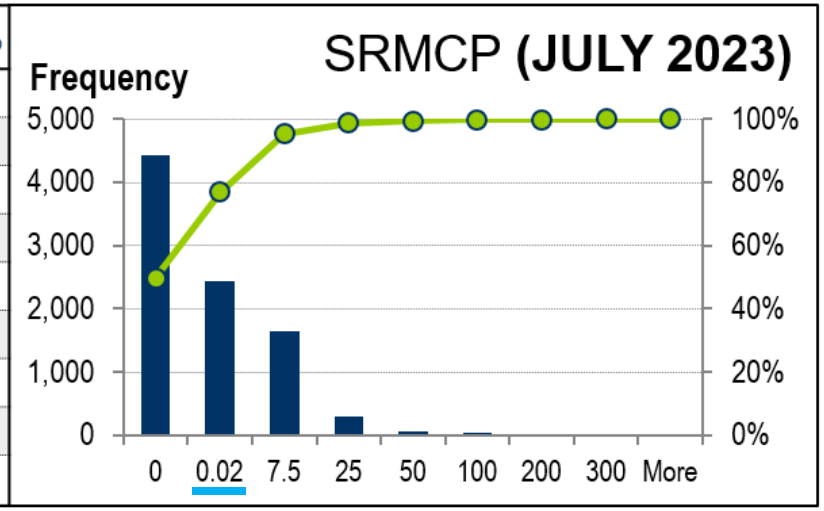
Price	Frequency	Cumulative %
0	2123	24.57%
0.02	4849	80.69%
7.5	1352	96.34%
25	262	99.38%
50	38	99.81%
100	11	99.94%
200	5	100.00%
300	0	100.00%
More	0	100.00%



Price	Frequency	Cumulative %
0	5317	59.55%
0.02	2327	85.62%
7.5	1150	98.50%
25	99	99.61%
50	18	99.81%
100	12	99.94%
200	5	100.00%
300	0	100.00%
More	0	100.00%



Price	Frequency	Cumulative %
0	4434	49.66%
0.02	2432	76.90%
7.5	1649	95.37%
25	302	98.76%
50	52	99.34%
100	37	99.75%
200	17	99.94%
300	4	99.99%
More	1	100.00%



Operational Reserves and Dispatched Reserves

Reserve capability formula are the same – business rules in Section 4 of Manual 11

OPERATIONAL RESERVES

- EMS reserve calculation
- Based on instantaneous energy and reserve data *(MW, Eco Limits, Ramp Rates)*
- Calculated every 15 seconds
- Separate status and calculations for components of units that are modeled as aggregates, for example Hydro

DISPATCHED RESERVES

- Markets reserve calculation
- Based on RTSCED case solution, which looks ahead to the target interval
- Updated after every RTSCED case approval *(typically every 5 minutes)*
- Aggregated units have a single status and reserve calculation

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Current Offer Structure and Pricing Outcomes for Reserves

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THINK BEFORE YOU CLICK!

Be alert to malicious phishing emails.

Report suspicious email activity to PJM.

(610) 666-2244 / it_ops_ctr_shift@pjm.com

Appendix

Acronyms

Acronym	Term & Definition
RT SCED	**Real-Time Security Constrained Economic Dispatch** is the application responsible for dispatching resources in real-time for a target five minute interval as a result of a co-optimization of Energy and Reserves for the forecasted system conditions..
LPC	**Locational Pricing Calculator** performs a pricing run solution to determine the Real-time LMP values and Regulation and Reserve Clearing Prices on a five (5) minute basis.
ASO	**Ancillary Service Optimizer** performs the joint optimization function of Energy, Reserves and Regulation in the dispatch run. The main functions of ASO are the clearing and commitment of Regulation resources and inflexible Reserve resources for a one hour time period
IT SCED	**Intermediate Term Security Constrained Economic Dispatch** solves a multi-interval, time-coupled solution to perform functions that include but not limited to resource commitment recommendations for Energy and Reserves, resource commitment decisions for economic Demand Resources, execution of the Three Pivotal Supplier Test for Energy

PJM Glossary

Acronyms

Acronym	Term & Definition
Condense Energy Usage	**Condense Energy Usage (MW) -** is the amount of advance notice, in hours, required to notify the operating company to prepare the unit to operate in synchronous condensing mode. The default value is 0 hours.
Condense Notification Time	**Condense Notification Time (hour)** is the amount of advance notice, in hours, required to notify the operating company to prepare the unit to operate in synchronous condensing mode. The default value is 0 hours.
Condense To Generate Time	Condense To Generate Time is the amount of time in hours it takes the unit to transition from condensing to generation.
Minimum Run Time	Minimum Run Time is the minimum number of hours a unit must run, in real-time operations, from the time after generator breaker closure to the time of generator breaker opening.

PJM Glossary

Acronyms

Acronym	Term & Definition
Synchronized Reserve Maximum (SR Max)	**SR Max -** is the highest incremental MW output level that a unit can reliably achieve while providing Synchronized Reserve
Secondary Reserve Maximum (SecR Max)	**SecR Max** is the highest incremental MW output level that a unit can reliably achieve while providing Secondary Reserve
SR	**Synchronized Reserve** is from resources that are electrically synchronized to the system, with the capability to be converted fully into energy within 10 minutes or customer load that can be removed from the system within 10 minutes of the request from the PJM dispatcher
NSR	**Non-Synchronized Reserve** is from resources that are offline, with the capability to be converted fully into energy within 10 minutes
SecR	**Secondary Reserve** is from resources with the capability to be converted fully into energy within a 10- to 30-minute interval following the request of PJM. Equipment providing Secondary Reserve need not be electrically synchronized to the power system.

PJM Glossary

Acronyms

Acronym	Term & Definition
MCP	**Market Clearing Price** is the Effective Cost of the marginal resource providing reserve to meet the requirement
ICCP	**Inter-Control Center Protocol** An industry standard protocol used to communicate real-time data between control centers. PJM uses this to send and receive operations analog data measurements and digital measurements.
DNP3	**Distributed Network Protocol 3** A set of communications protocols used between components in process automation systems. Its main use is in utilities such as electric and water companies. Usage in other industries is not common.

PJM Glossary